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FLIGHT TESTS OF DIVE-RECOVERY FLAPS ON AN XP-51 AIRPLANE

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NACA

WASHINGTON

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SUMMARY

A flight investigation was made to determine the effectiveness of dive-recovery flaps installed on the XP-51 airplane as a safety device for recovery from contemplated terminal-velocity dives. This dive-recovery-flap installation is described and results are presented of measurements obtained during stick-free pull-ups and pull-outs made by deflecting the dive-recovery flaps to two selected values of flap angle. Tests were made for a range of Mach numbers to 0.76 at an altitude of approximately 20,000 feet.

The results of the tests showed that the flap effectiveness decreased after a Mach number of 0.65 was reached and indicated that a satisfactory dive recovery could be made by deflecting the dive-recovery flaps 21.5° at Mach numbers up to the estimated terminal Mach number of the airplane. Results calculated from data obtained in tests using a 30° flap deflection indicated that the design load factor may be exceeded during high-speed dive recoveries at altitudes below 15,000 feet. The tests further showed that no buffeting occurred when the flaps were deflected and that no rolling of the airplane was encountered during tests when the flaps were deflected unequally.

INTRODUCTION

Considerable difficulty has been encountered in recovering from high-speed dives with present-day fighter airplanes. (See reference 1.) Unpublished wind-tunnel tests of the Lockheed P-38 airplane and flight tests of the Republic P-47 airplane have shown that dive-recovery flaps, which are small auxiliary flaps on the under surface of the wing, are effective in producing the acceleration required to effect a dive pull-out at high speeds, even when other controls prove useless. The North American XP-51 airplane, on which dive tests up to the terminal Mach number were being made, was therefore equipped with dive-recovery flaps as a safety measure.

Tests of the dive-recovery flaps were made as part of the general program of dive tests. A description of the design and installation of dive-recovery flaps is presented herein together with data obtained in flight to determine their effectiveness.

APPARATUS

Airplane.- Tests were made of the dive-recovery flaps installed on an XP-51 airplane. A photograph of the airplane is shown in figure 1 and pertinent dimensions and data are given in the following table:

Airplane	
Over-all length	32 ft $2\frac{5}{8}$ in.
Height	11 ft 9 in.
Gross weight (at take-off)	7870
Center of gravity (at take-off), percent mean aerodynamic chord	28.4
Engine	Allison V-1710-83
Rating:	
Take-off	1150 horsepower at 2800 rpm and 46.8 in. mercury at sea level
Military	1150 horsepower at 3000 rpm and 45.9 in. mercury at 9600 ft
Normal	1000 horsepower at 2600 rpm and 39.5 in. mercury at 9000 ft
Propeller	Curtiss constant-speed
Diameter	10 ft 6 in.
Number of blades	3

Wing

Area, sq ft	235.75
Span, ft	37.03
Mean aerodynamic chord, in.	79.60
Leading edge of mean aerodynamic chord relative to leading edge of root chord, in.	8.0 above 6.1 behind

Horizontal tail

Area, sq ft	41.8
Span, in.	158.0

Dive-recovery flaps.- The dive-recovery flaps were designed and installed at the Langley Laboratory of the NACA. The size and location of the dive-recovery flaps are shown in figure 2. These flaps were constructed of 1/4-inch mild steel, were attached at the leading edge by a piano hinge, and were hydraulically operated. External views of the flap installation are shown in figure 3. The size and location of the flaps were selected to simulate as nearly as possible the dive-recovery flaps on the P-47C airplane. The relative size and location of the flaps, based on wing dimensions, on the P-47C and XP-51 airplanes is shown in the following table:

Airplane	Ratio of flap span to wing span	Ratio of flap chord to wing chord	Ratio of flap area to wing area	Location of inboard end of flap, percent semispan from plane of symmetry	Chordwise location of flap hinge line, percent local wing chord
P-47C	0.1960	0.0796	0.0166	25.3	30.0
XP-51	.1350	.0875	.0124	32.8	31.7

The ratio of flap span to flap chord was somewhat different for the XP-51 airplane from the ratio for the P-47C airplane. This difference, however, could not be avoided since the flap span of the XP-51 airplane was limited by structural considerations, and the chord was increased to maintain an area proportional to the area of the flap of the P-47C airplane. These same structural considerations prevented placing the dive-recovery flap as far inboard as the dive-recovery flap on the P-47C airplane. An attempt was made, however, to have as much of the flap as possible in front of the horizontal tail, since wind-tunnel tests have shown that a part of the effectiveness of the flaps is due to a change in downwash at the tail. An initial dive-recovery flap deflection of 30° was used, because experience has shown that greater deflections would cause serious buffeting.

Instruments.- In the tests of the dive-recovery flaps on the XP-51 airplane, standard NACA recording instruments, synchronized by means of a timer, were used to obtain the following quantities:

Indicated airspeed
Normal and longitudinal acceleration
Altitude
Elevator position
Dive-recovery-flap position
Elevator and aileron stick forces
Pitching angular velocity
Pressure variation at orifice on upper surface of stabilizer (see fig. 2)

Temperature of the free air was obtained from an indicating resistance thermometer corrected for adiabatic rise.

SYMBOLS

Δn incremental normal acceleration, g units

ΔF_e elevator stick-force increment, pounds

x longitudinal position of center of gravity, percent mean aerodynamic chord

Δx percent change in center-of-gravity position from selected value

dF_e/dn stick force per g, pounds per g

δ_f dive-recovery-flap deflection, degrees

ρ standard air density, slugs per cubic foot

a	velocity of sound, feet per second
W	gross weight of airplane, pounds
M	Mach number
δ_e	elevator deflection, degrees

TESTS, RESULTS, AND DISCUSSION

The characteristics of the dive-recovery flaps on the XP-51 airplane were investigated at Mach numbers ranging from 0.27 to 0.76. The airplane was trimmed for zero stick force in gliding flight at a given speed and then the dive-recovery flaps were deflected. Records were taken of the dive-recovery-flap deflection and the ensuing maneuver. The pilot was instructed to simulate the stick-free condition during the maneuver and to use control only to prevent excessive accelerations. The test runs were all made at a pressure altitude of approximately 20,000 feet.

Time histories of use of the dive-recovery flaps with the initial dive-recovery-flap deflection of 30° are shown in figures 4 to 10. These figures show that the increase in normal acceleration due to use of the dive-recovery flaps is smooth and similar to that which a pilot would effect in a dive pull-out. It may be noted that even though in several of these maneuvers the dive-recovery flaps did not deflect equally, the pilot reported no appreciable rolling, which indicates that some differential-flap action can be tolerated. The time histories of pressure coefficient p/q at an orifice on the upper surface of the horizontal tail (fig. 2) were used to determine whether any tail buffeting occurred during use of the dive-recovery flaps. The data confirmed the pilot's opinion that no buffeting occurred. The size and length of tubing connecting the orifice to the recording pressure cell was such that oscillations of about 25 cycles per second or less could easily be recorded.

From the data given in figures 4 to 10, the change in normal acceleration Δn due to use of the dive-recovery flaps at various Mach numbers was determined.

These values of Δn are given in table I. In evaluating these data the Mach number was taken at the time of application of the dive-recovery flaps; the altitude and flap deflection used were those at which maximum acceleration occurred. In the case of unequal dive-recovery-flap deflection, a mean value of right and left dive-recovery-flap deflection was used. In figures 4 to 10 some slight variations in the altitude and dive-recovery-flap deflection, which tend to introduce scatter in the measured results, are shown to occur at the time of maximum acceleration. In addition, some experimental scatter resulted from the pilot's applying small amounts of elevator stick force during the maneuver and from slight differences in the weight and center-of-gravity position for the various runs. Because of these differences, the values of normal acceleration due to use of the dive-recovery flaps were corrected to the following selected conditions:

Change in elevator stick force during maneuver	0
Altitude, feet	20,000
Flap deflection, degrees	30
Weight, pounds	7750
Center-of-gravity position, percent mean aerodynamic chord	28.4

In correcting the data to the foregoing conditions, it was assumed that the operation of the dive-recovery flaps does not change the slope of the wing-lift curve, that the effect of the dive-recovery flaps is linear within a small range of flap deflections on either side of the selected flap deflection, and that the resultant change in normal acceleration or change in lift coefficient is independent of the lift coefficient for trim with the dive-recovery flaps undeflected.

The values of incremental normal acceleration were corrected to zero change in elevator stick force and only the elevator stick forces were corrected for center-of-gravity position by the following equation:

$$(\Delta n)_{\Delta F_e=0} = \Delta n + \frac{\Delta F_e}{\left(\frac{dF_e}{dn}\right)_s + \left[\frac{d\left(\frac{dF_e}{dn}\right)}{dx}\Delta x\right]}$$

where subscript s denotes the selected conditions previously specified. The value of Δn was not corrected for change in center-of-gravity position because the effect of this variable had not been determined from flight tests. It is thought, however, that such a correction would have a larger effect on the measured results than the correction obtained from $\dfrac{d\left(\dfrac{dF_e}{dn}\right)}{dx}\Delta x$.

The values of dF_e/dn and the rate of change of dF_e/dn with center-of-gravity position were determined from the flight tests as 8.5 and 1.2, respectively, for the selected center-of-gravity position. In determining ΔF_e, stick-force increments of less than 1 pound were ignored since such values would be within the accuracy of the control-force recorder. The increment ΔF_e was determined as any change in applied stick force that would contribute to a change in the acceleration resulting from deflection of the dive-recovery flaps. The values of ΔF_e and Δx used are given in table I. Values of incremental normal acceleration corrected for stick-force change and center-of-gravity position are also given in table I.

The values of incremental acceleration Δn were corrected to the selected altitude, flap deflection, and weight by the following equation:

$$\Delta n_s = (\Delta n)_{\Delta F_e=0}\left(\frac{\rho_s {a_s}^2}{\rho a^2}\right)\left(\frac{\delta_{f_s}}{\delta_f}\right)\left(\frac{W}{W_s}\right)$$

Values of Δn_s are given in table I. These values are shown plotted against Mach number in figure 11. Curves are also given in figure 11, which show the effect of the dive-recovery flaps at altitudes ranging from 10,000 to 25,000 feet. These curves were derived by the following equation:

$$\frac{\Delta n_{alt}}{\Delta n_{20,000\text{ ft}}} = \frac{(\rho a)^2{}_{alt}}{(\rho a^2)_{20,000\text{ ft}}}$$

In calculating the effect of the dive-recovery flaps at altitudes other than 20,000 feet, the same assumption was made as in correcting the data to the selected altitude - that is, the resultant change in normal acceleration is independent of the lift coefficient required to trim the airplane with the dive-recovery flaps undeflected. As can be seen in figure 11, dive-recovery flaps deflected 30° can cause acceleration increments at the lower altitudes in excess of the design load factor of the airplane. When this possibility became evident, the dive-recovery-flap deflection was reduced to 21.5° and tests were repeated.

Figures 12 to 21 are time histories of the test runs made with the dive-recovery flaps deflected 21.5°. The change in normal acceleration with Mach number was determined and the values of incremental acceleration were corrected to the selected conditions in the same way as for the tests of the dive-recovery flaps deflected 30°. The variation of change in normal acceleration due to deflecting the dive-recovery flaps 21.5° with Mach number is shown in figure 22. The curve shown for the variation of normal acceleration with Mach number at an altitude of 20,000 feet was obtained from the corrected test results and the curves for other altitudes were calculated on the basis of these results. Figure 22 shows that the dive-recovery flaps set at 21.5° will produce an adequate stick-free dive recovery at all practical altitudes within the Mach number range tested without exceeding the limit load factor of the airplane.

Figures 11 and 22 show that the maximum effectiveness of the dive-recovery flap when deflected occurs at a Mach number of approximately 0.65 with a decrease in effectiveness as the Mach number is increased. Also, no consistent trend is apparent when test values of either flap-deflection setting are corrected to 21.5° or to 30°; therefore the effect of the flaps can be considered to be linear between these two angles.

Tests to terminal Mach number of the airplane, which is estimated to be 0.82, have not been made using the dive-recovery flaps. The present data, however, indicated that the dive-recovery flaps would in an emergency effect a satisfactory dive recovery at the estimated terminal Mach number of the XP-51 airplane.

The elevator deflections that would cause a change in longitudinal trim equivalent to that caused by deflecting the dive-recovery flaps were determined by flying with the flaps undeflected and with the flaps deflected 30°. The data obtained are given in figure 23, which shows that deflecting the dive-recovery flaps 30°, in the Mach number range tested, would result in a normal acceleration corresponding to that obtained with approximately 2° change in elevator deflection. At very high Mach numbers, however, the elevators may become relatively less effective in producing a change in normal acceleration.

Wind-tunnel tests have shown that the change in longitudinal trim provided by the dive-recovery flaps at high Mach numbers is caused by a change in pitching moment of the wing and by a change in angle of attack of the tail. The effect of change in pitching moment of the wing is rather small compared with the effect of the change in angle of attack at the tail when the dive-recovery flaps are placed at about one-third of the wing chord behind the leading edge. If the flaps are installed farther back on the wing, the wing pitching moment becomes negative and is of such magnitude as to cause an appreciable reduction in the effect of the dive-recovery flaps. The two factors that contribute to the angle-of-attack change at the tail are: (1) a decrease in angle of attack to maintain the same lift (change in the angle of zero lift), and (2) a change in downwash at the tail due to a change in spanwise loading on the wing. The change in downwash at the tail due to the altered spanwise loading can be seen to be greatest when the dive-recovery flaps are directly ahead of the tail.

Available data indicated that selection of satisfactory dive-recovery flaps for any conventional airplane is possible. The flaps should be located approximately one-third of the wing chord behind the leading edge and should be ahead of the horizontal tail. The selection of dimensions of the dive-recovery flaps should be based on wing dimensions as in the present case. Somewhat smaller dive-recovery flaps could probably be tolerated if the dive-recovery-flap deflection were increased. The rate of dive-recovery-flap deflection should be similar to that used in the present tests since lower rates might result in a slower recovery with a resultant greater loss of altitude in recovery even though the same value of maximum acceleration would finally be reached. Flight tests, as in the present investigation, will probably be necessary to obtain the final flap configuration, but a step-by-step test program similar to the one described herein can be conducted with a minimum amount of danger involved.

CONCLUSIONS

From results of flight tests to determine the effectiveness of dive-recovery flaps as installed on the North American XP-51 airplane the following conclusions were drawn:

1. The dive-recovery flaps on the XP-51 airplane provided a smooth dive recovery at high speeds with little lag between deflection of the flaps and the resultant acceleration.

2. The effectiveness of the dive-recovery flaps varied linearly with deflection within the deflection range tested.

3. The effectiveness of the dive-recovery flaps increased with an increase in Mach number up to 0.65 and then gradually decreased with further increase in Mach number.

4. No buffeting resulted from the use of the dive-recovery flaps at any speed tested and no rolling of the airplane was encountered during tests when the flaps were deflected unequally.

5. The data indicate that the dive-recovery flaps used on the XP-51 airplane, when deflected 21.5°, will probably effect satisfactory dive recovery up to the estimated terminal Mach number for the airplane without exceeding the design load factor anywhere in the speed range. Results calculated from data obtained in tests using a 30° flap deflection indicated that the

design load factor may be exceeded at high speed at altitudes below 15,000 feet.

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REFERENCE

1. Hood, Manley J., and Allen, H. Julian: The Problem of Longitudinal Stability and Control at High Speeds. NACA CB No. 3K18, 1943.

TABLE I.- SUMMARY OF PERTINENT MEASURED AND CORRECTED DATA

OBTAINED DURING DIVE-RECOVERY-FLAP DEFLECTION

Figure	Δn (g)	ΔF_e (lb)	Δx (percent M.A.C.)	Δn corrected for zero stick force and to a selected center-of-gravity position	Δn_s (Δn corrected for selected altitude and weight and a flap deflection of 30°)	Δn_s, (Δn corrected for selected altitude and weight, and a flap deflection of 21.5°)
Dive-recovery-flap deflection, 30°						
4	4.60	2.50	-0.31	4.98	5.64	4.04
5	4.80	2.00	-.23	5.04	5.38	3.86
6	4.20	3.00	-.15	4.56	4.86	3.48
7	3.75	6.50	-.07	4.52	5.12	3.67
8	4.35	2.00	.04	4.58	4.42	3.17
9	5.8	3.00	.35	6.15	5.70	4.08
10	6.15	3.50	.67	6.56	6.03	4.32
Dive-recovery-flap deflection, 21.5°						
12	0.24	-----	0.04	0.24	0.34	0.24
13	.60	-----	.12	.60	.82	.59
14	1.44	-1.25	.20	1.29	1.77	1.26
15	2.11	1.00	.28	2.23	3.11	2.22
16	2.96	2.00	.35	3.19	4.19	3.00
17	2.68	1.00	.43	2.80	3.69	2.64
18	4.45	1.00	.12	4.57	6.11	4.37
19	4.6	1.50	.28	4.77	6.18	4.42
20	4.55	1.00	.43	4.66	5.84	4.17
21	3.95	5.00	.59	4.49	5.37	3.84

Figure 1.- Three-quarter front view of the XP-51 airplane.

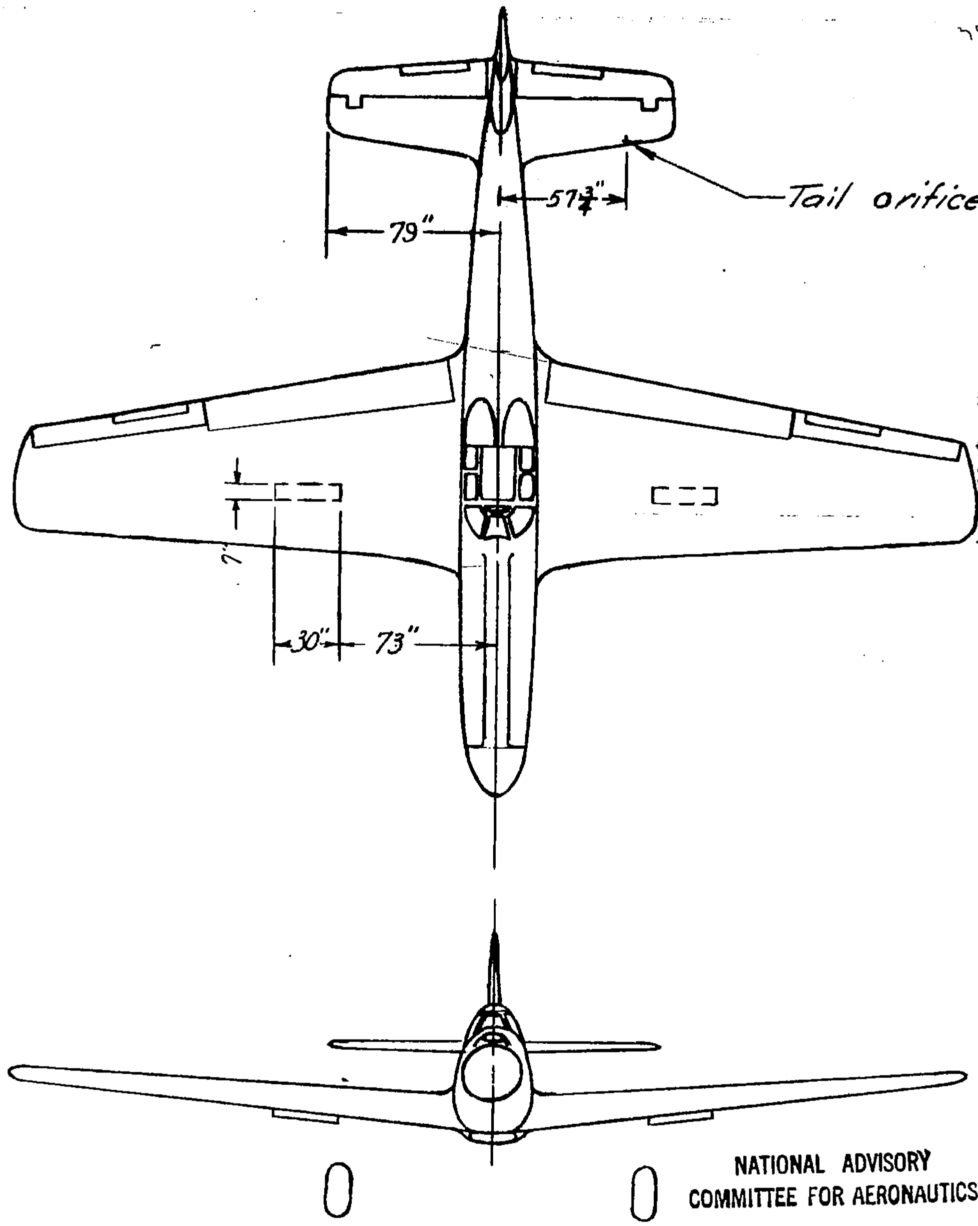
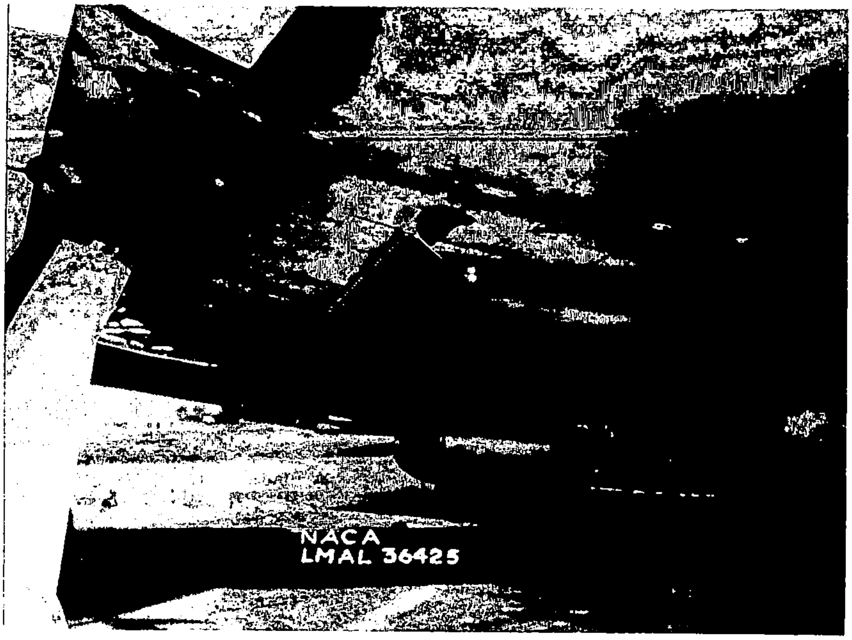
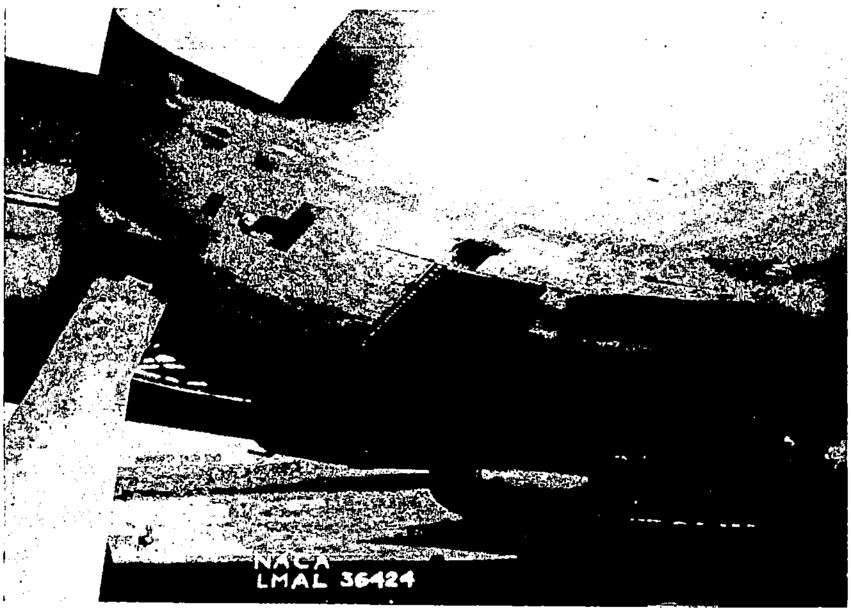


Figure 2.- Location of dive-recovery flaps on the XP-51 airplane.



(a) Flap deflected 30°.



(b) Flap fully retracted.

Figure 3.- Dive-recovery flap located on left wing of the XP-51 airplane.

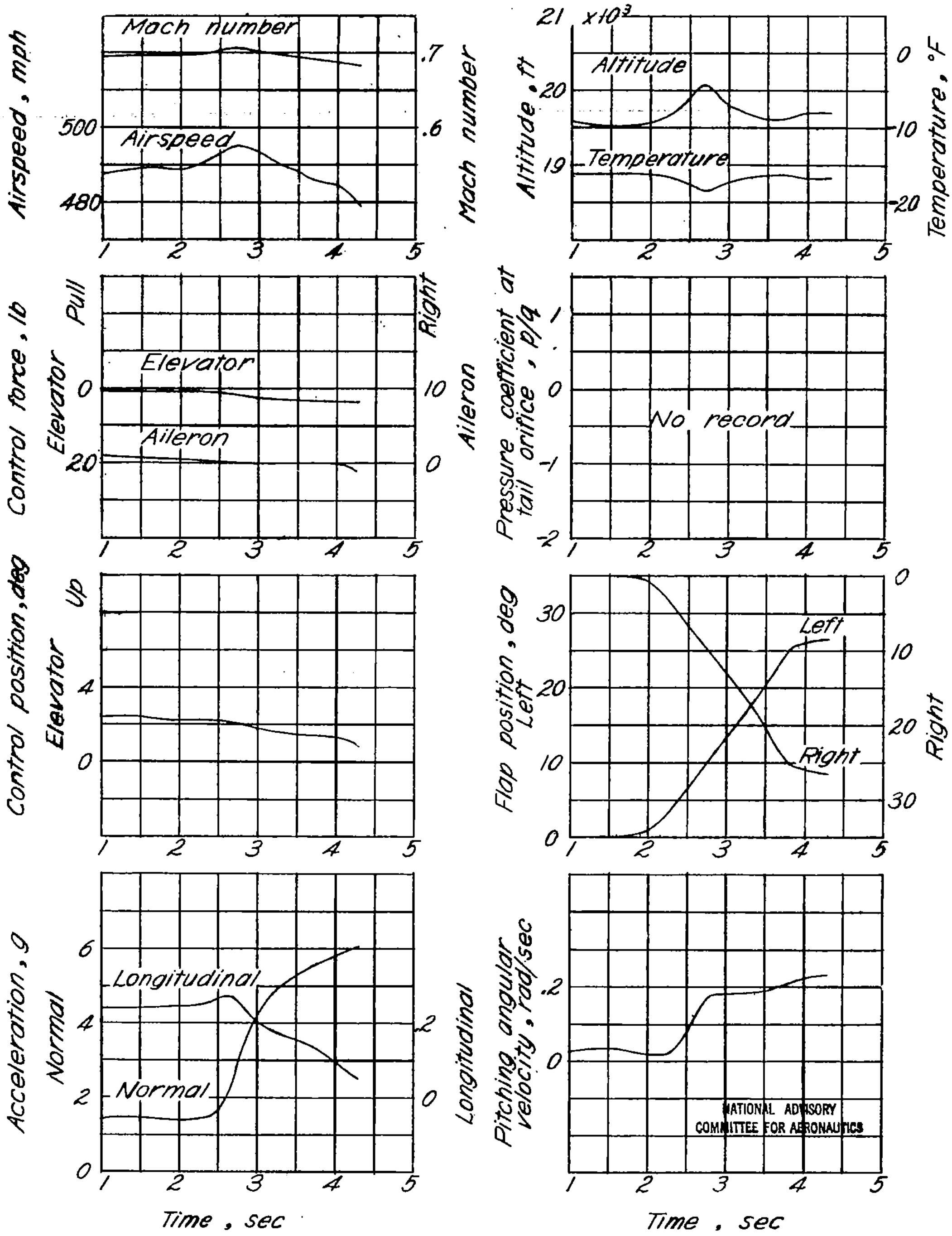


Figure 4.- Variation of basic measured quantities during dive-recovery-flap deflection. Dive-recovery-flap deflection, 30°; weight, 7870 pounds; center-of-gravity position, 28.71 percent mean aerodynamic chord.

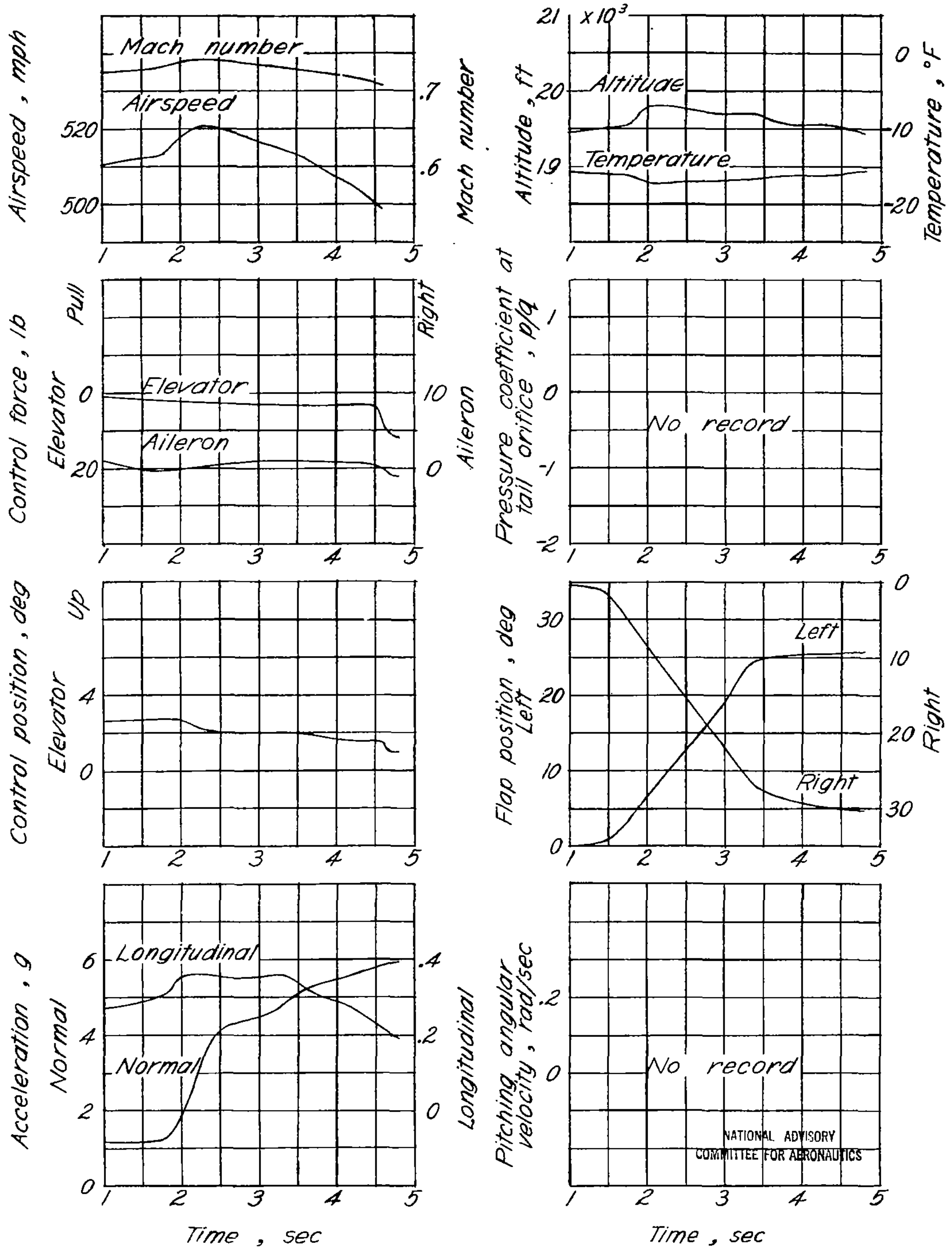


Figure 5.- Variation of basic measured quantities during dive-recovery-flap deflection. Dive-recovery-flap deflection, 30°; weight, 7850 pounds; center-of-gravity position, 28.63 percent mean aerodynamic chord.

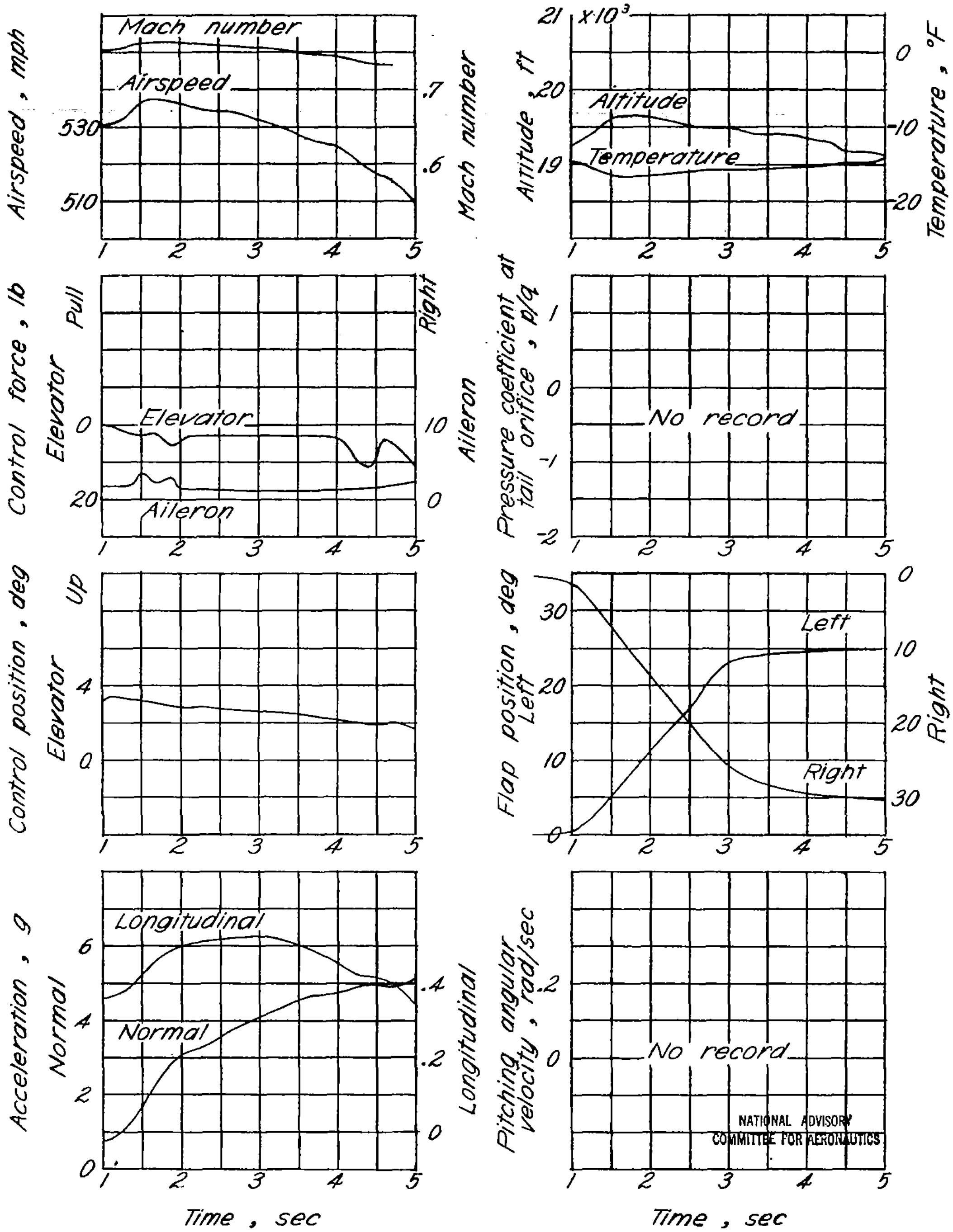


Figure 6.- Variation of basic measured quantities during dive-recovery-flap deflection. Dive-recovery-flap deflection, 30°; weight, 7810 pounds; center-of-gravity position, 28.55 percent mean aerodynamic chord.

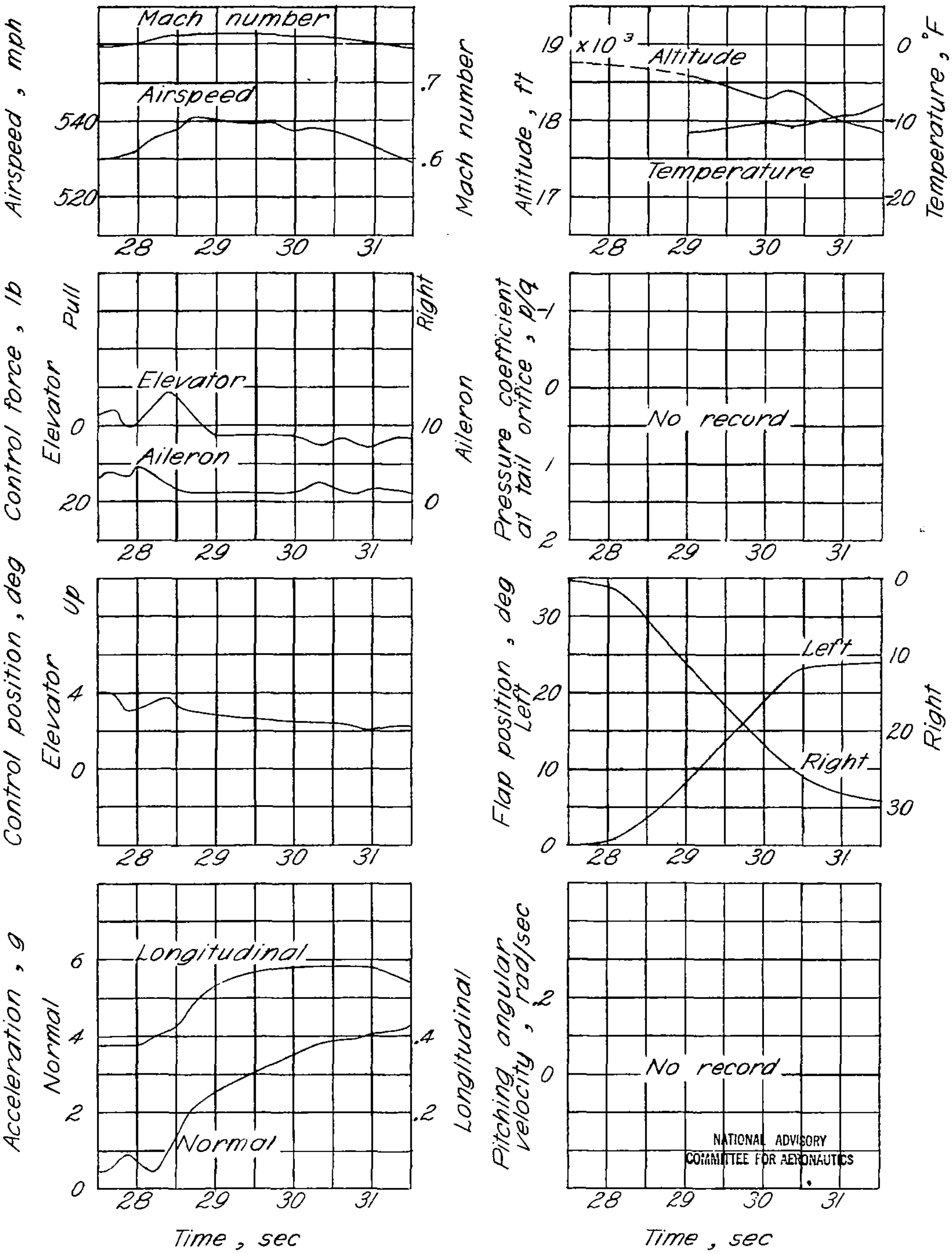


Figure 7.- Variation of basic measured quantities during dive-recovery-flap deflection. Dive-recovery-flap deflection, 30°; weight, 7780 pounds; center-of-gravity position, 28.47 percent mean aerodynamic chord.

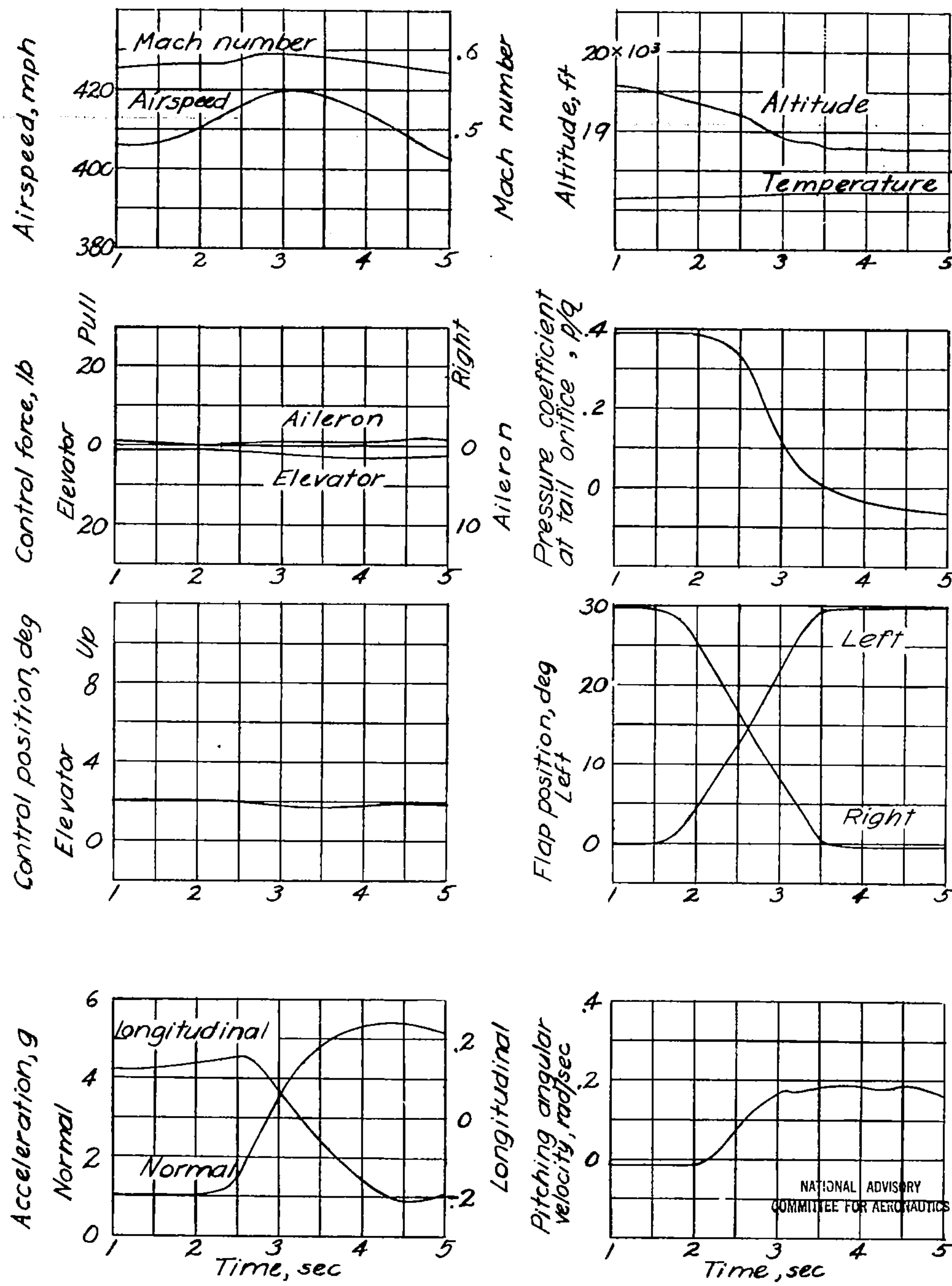


Figure 8.- Variation of basic measured quantities during dive-recovery-flap deflection. Dive-recovery-flap deflection, 30°; weight, 7870 pounds; center-of-gravity position, 28.36 percent mean aerodynamic chord.

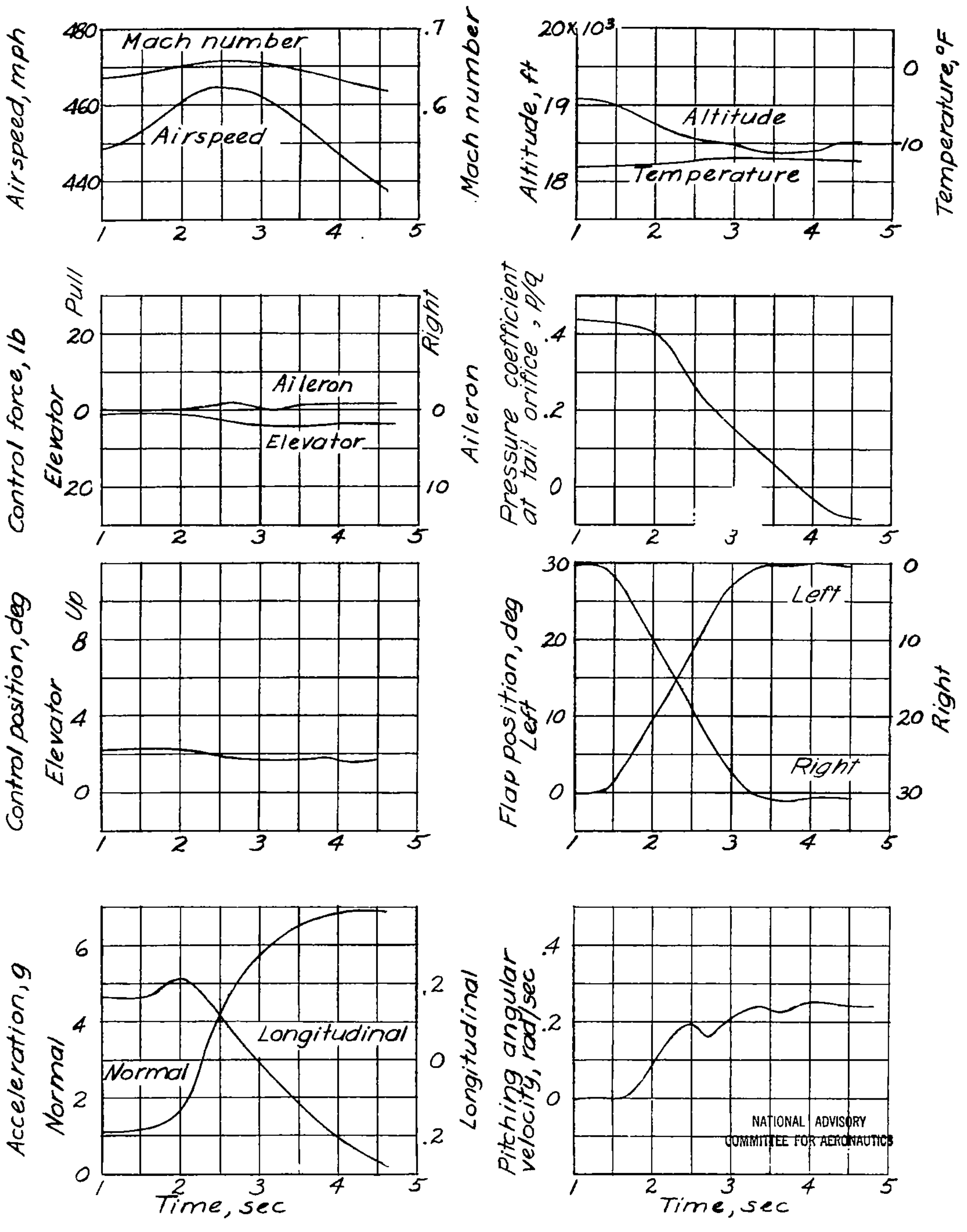


Figure 9.- Variation of basic measured quantities during dive-recovery-flap deflection. Dive-recovery-flap deflection, 30°; weight, 7750 pounds; center-of-gravity position, 28.05 percent mean aerodynamic chord.

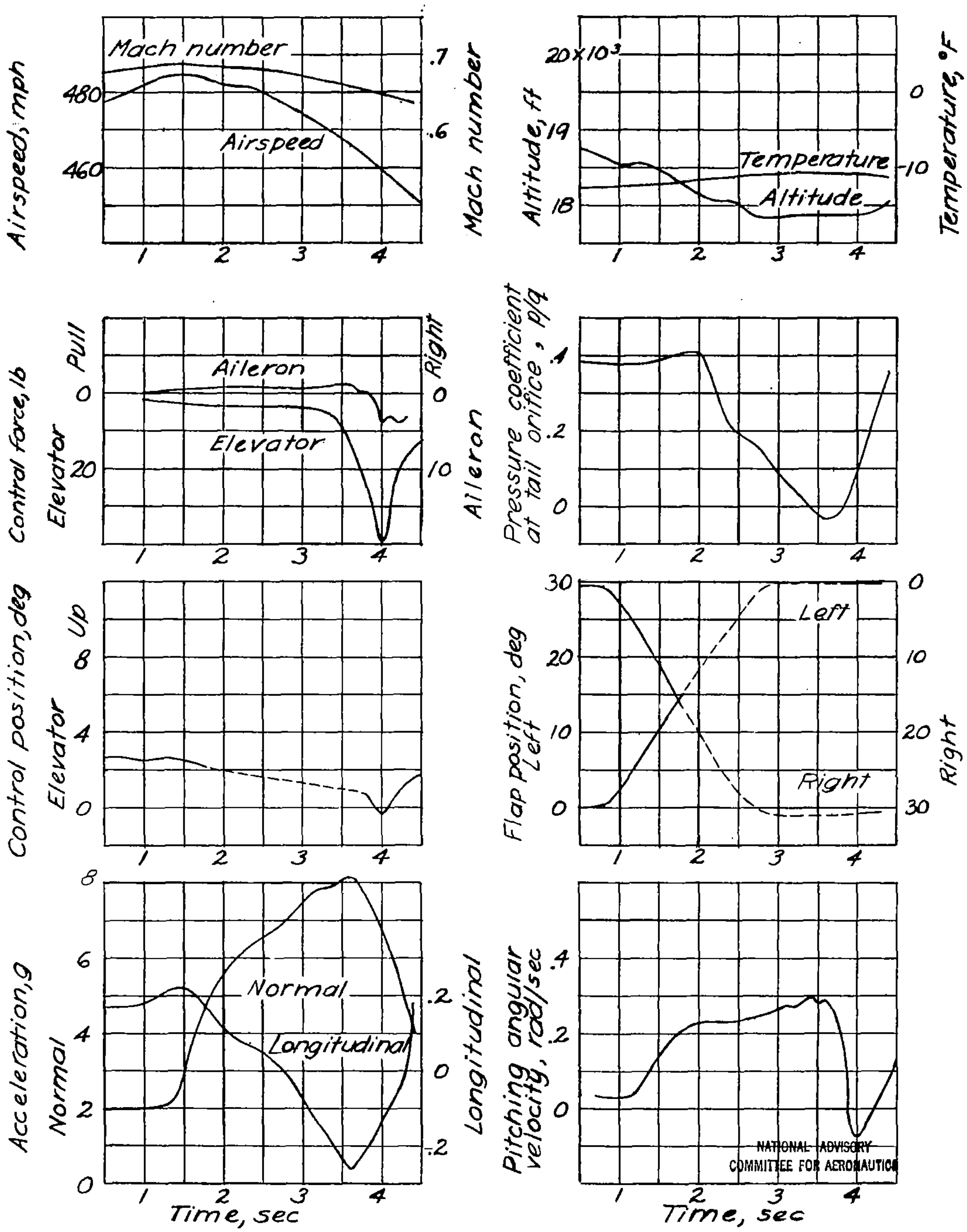


Figure 10.- Variation of basic measured quantities during dive-recovery-flap deflection. Dive-recovery-flap deflection, 30°; weight, 7630 pounds; center-of-gravity position, 27.73 percent mean aerodynamic chord.

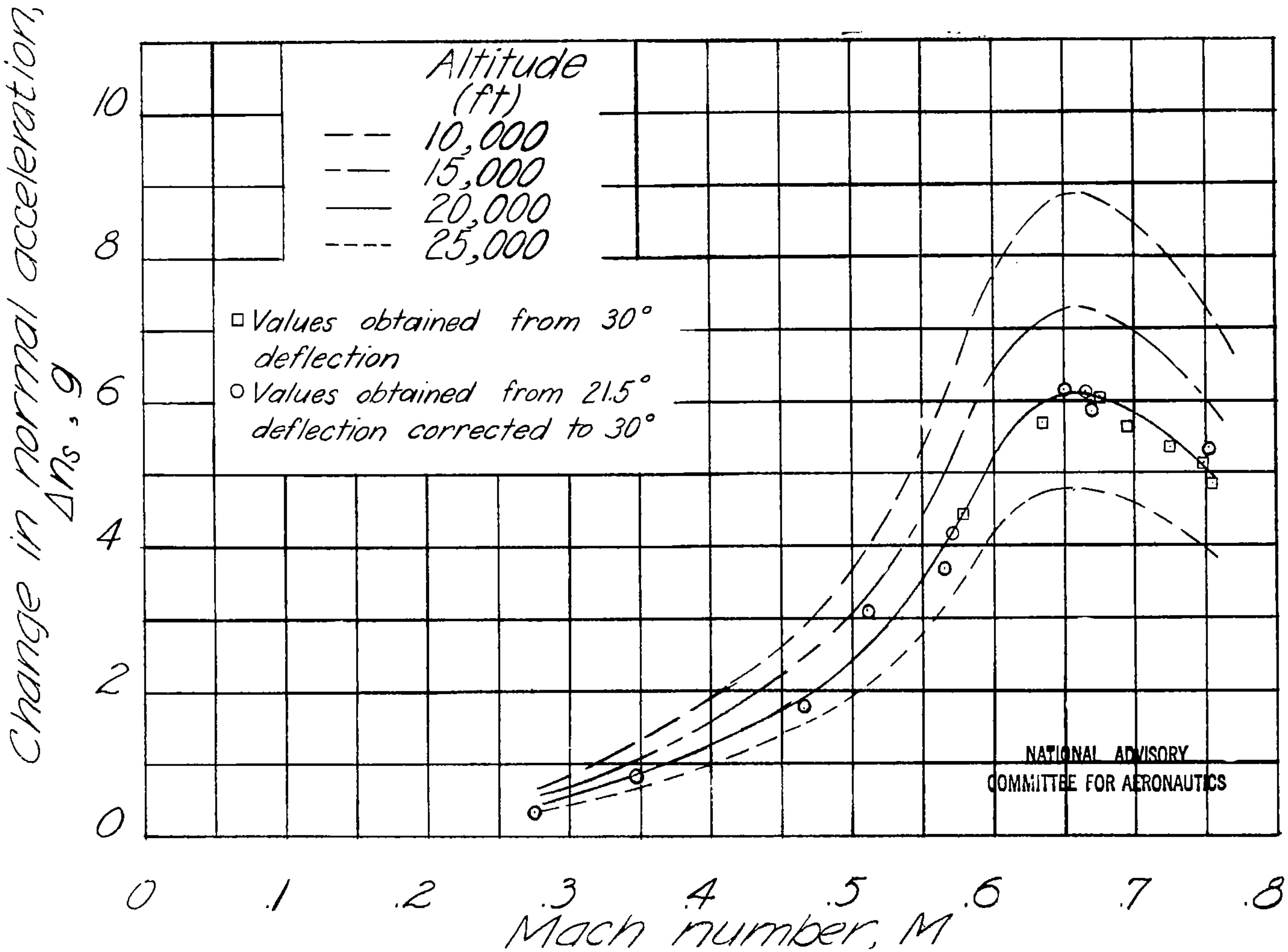


Figure 11.- Variation of normal acceleration due to use of the dive-recovery flaps with Mach number at various altitudes. Dive-recovery-flap deflection 30°; XP-51 airplane.

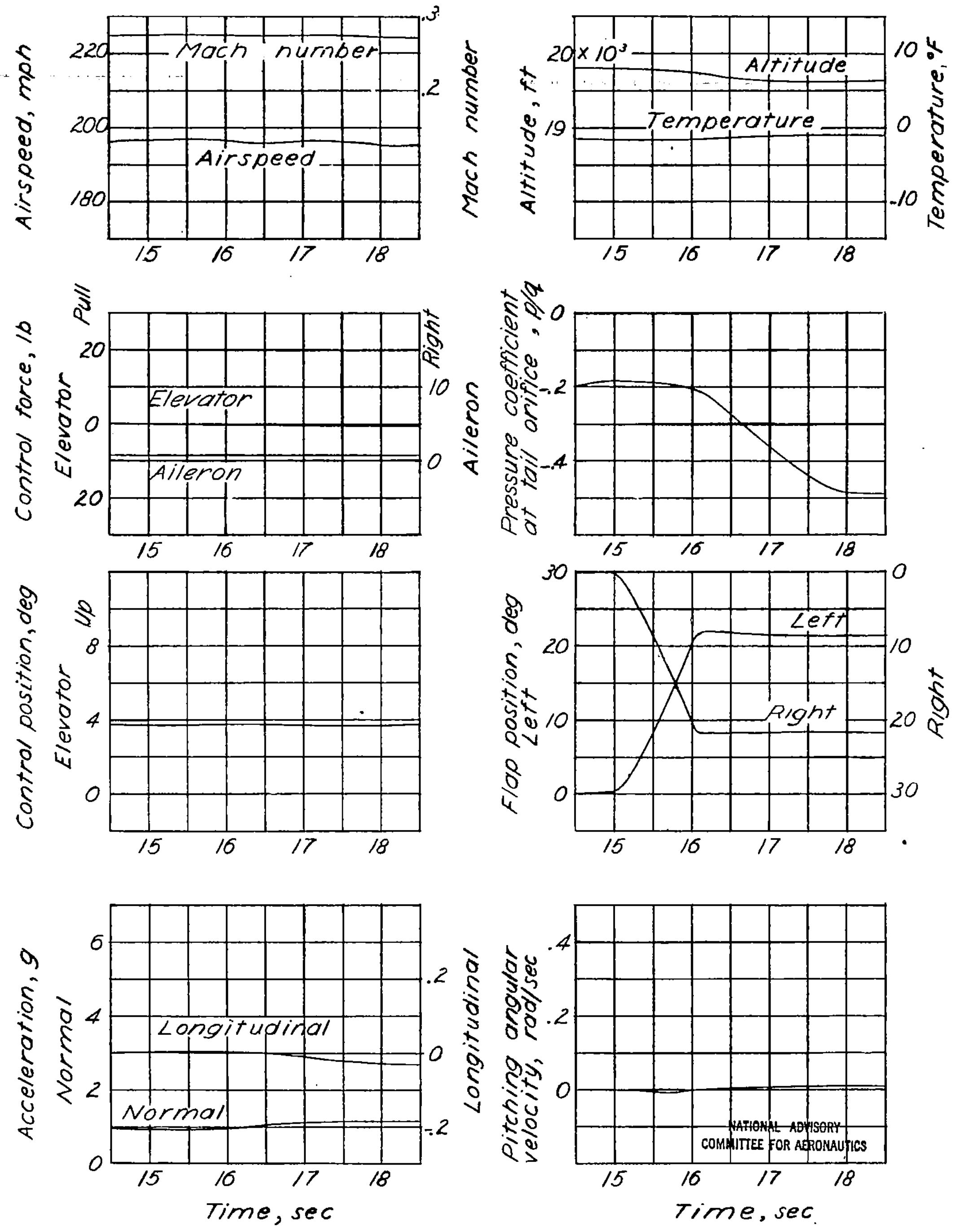


Figure 12.- Variation of basic measured quantities during dive-recovery-flap deflection. Dive-recovery-flap deflection, 21.5°; weight, 7870 pounds; center-of-gravity position, 28.36 percent mean aerodynamic chord.

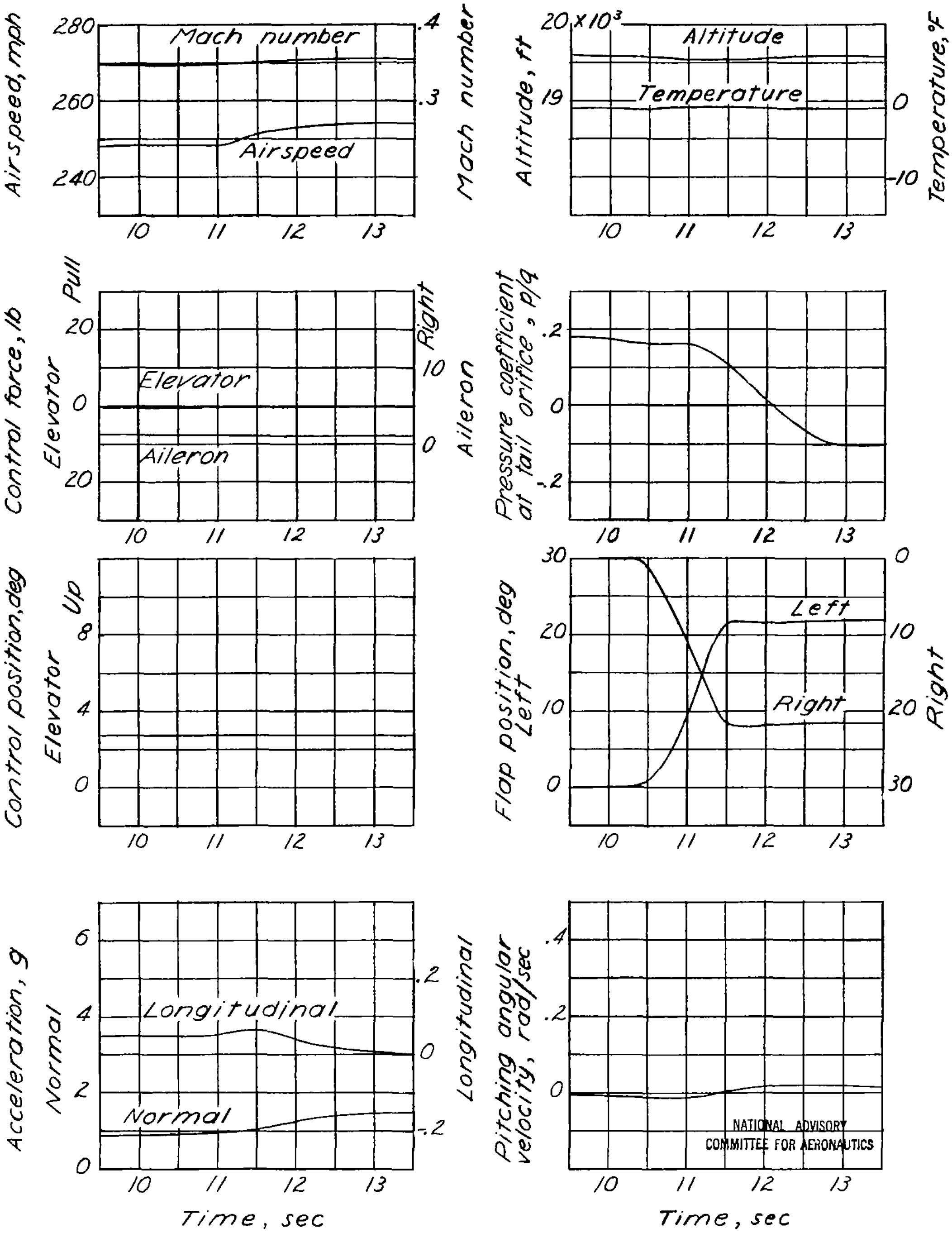


Figure 13.- Variation of basic measured quantities during dive-recovery-flap deflection. Dive-recovery-flap deflection, 21.5°; weight, 7870 pounds; center-of-gravity position, 28.28 percent mean aerodynamic chord.

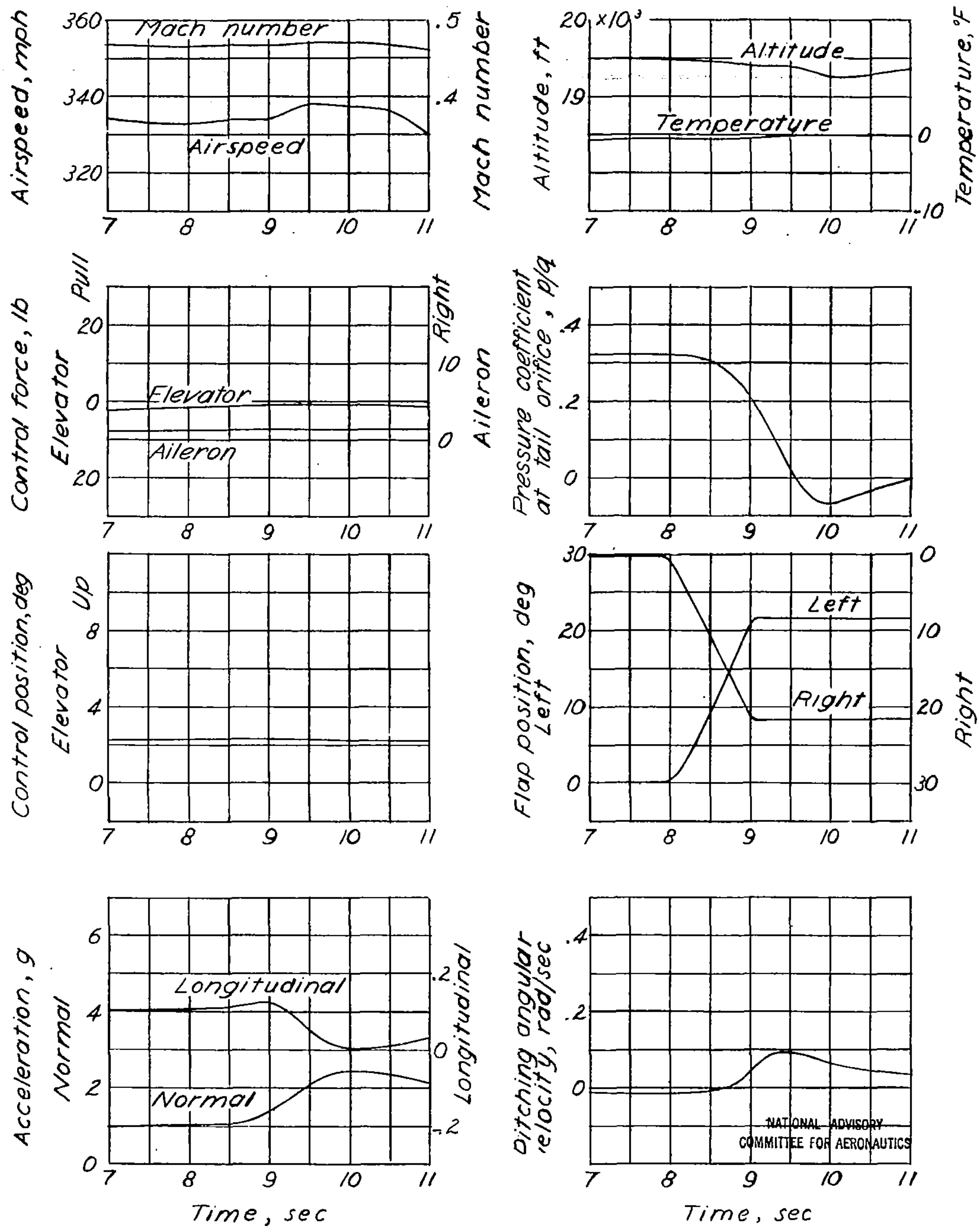


Figure 14.- Variation of basic measured quantities during dive-recovery-flap deflection. Dive-recovery-flap deflection, 21.5°: weight, 7810 pounds; center-of-gravity position, 28.20 percent mean aerodynamic chord.

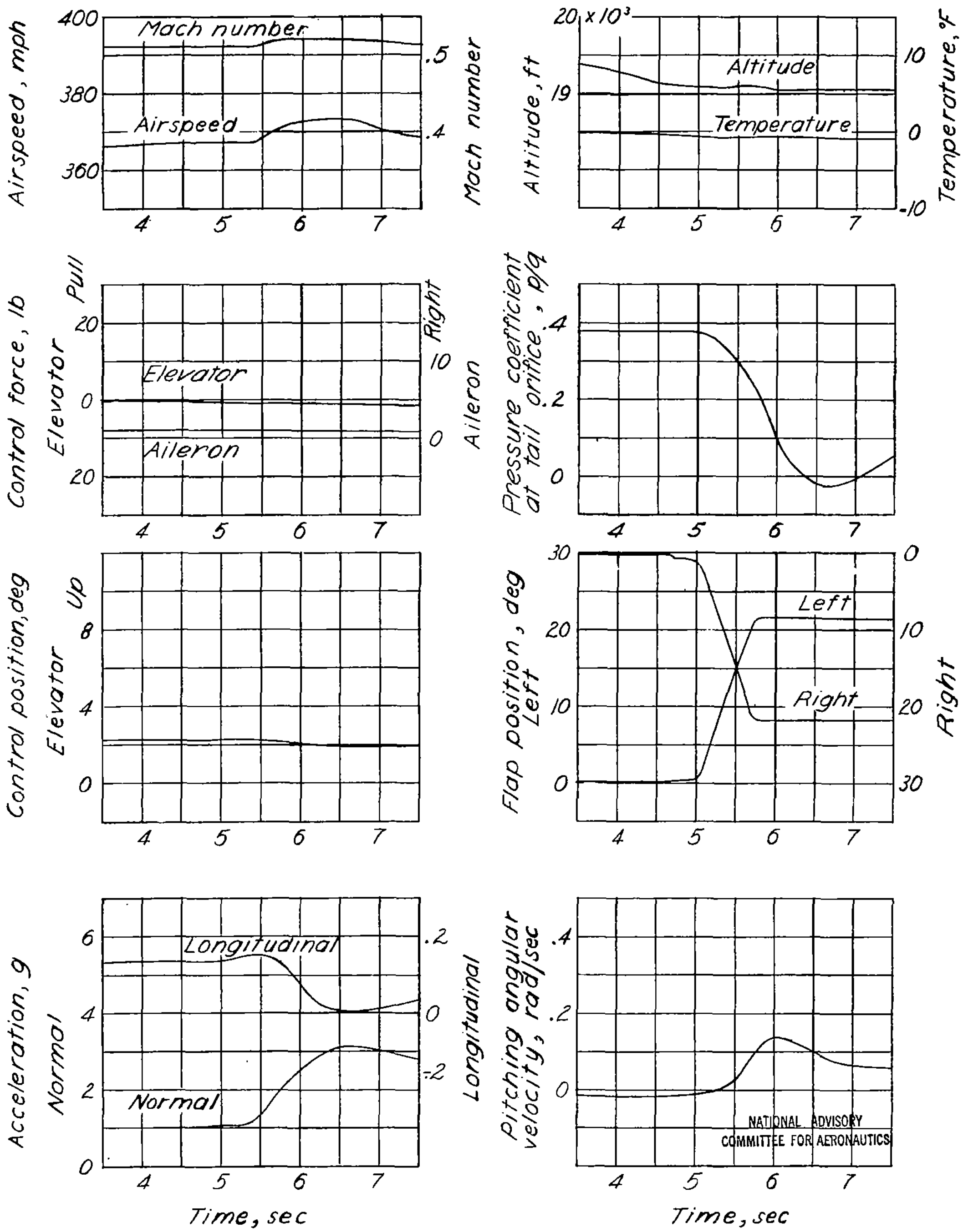


Figure 15.- Variation of basic measured quantities during dive-recovery-flap deflection. Dive-recovery-flap deflection, 21.5°; weight, 7780 pounds; center-of-gravity position, 28.12 percent mean aerodynamic chord.

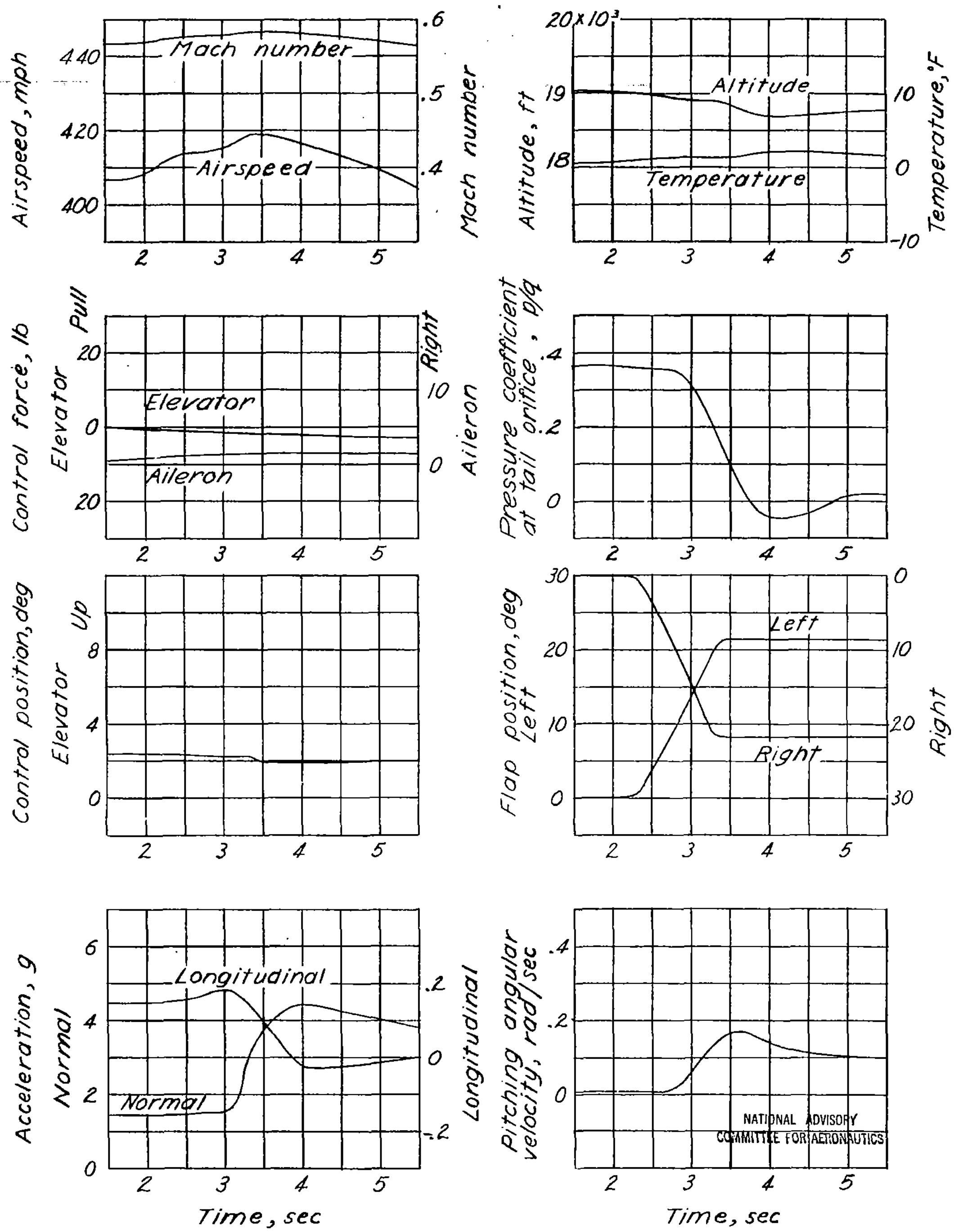


Figure 16.- Variation of basic measured quantities during dive-recovery-flap deflection. Dive-recovery flap deflection, 21.5°; weight, 7750 pounds; center-of-gravity position, 28.05 percent mean aerodynamic chord.

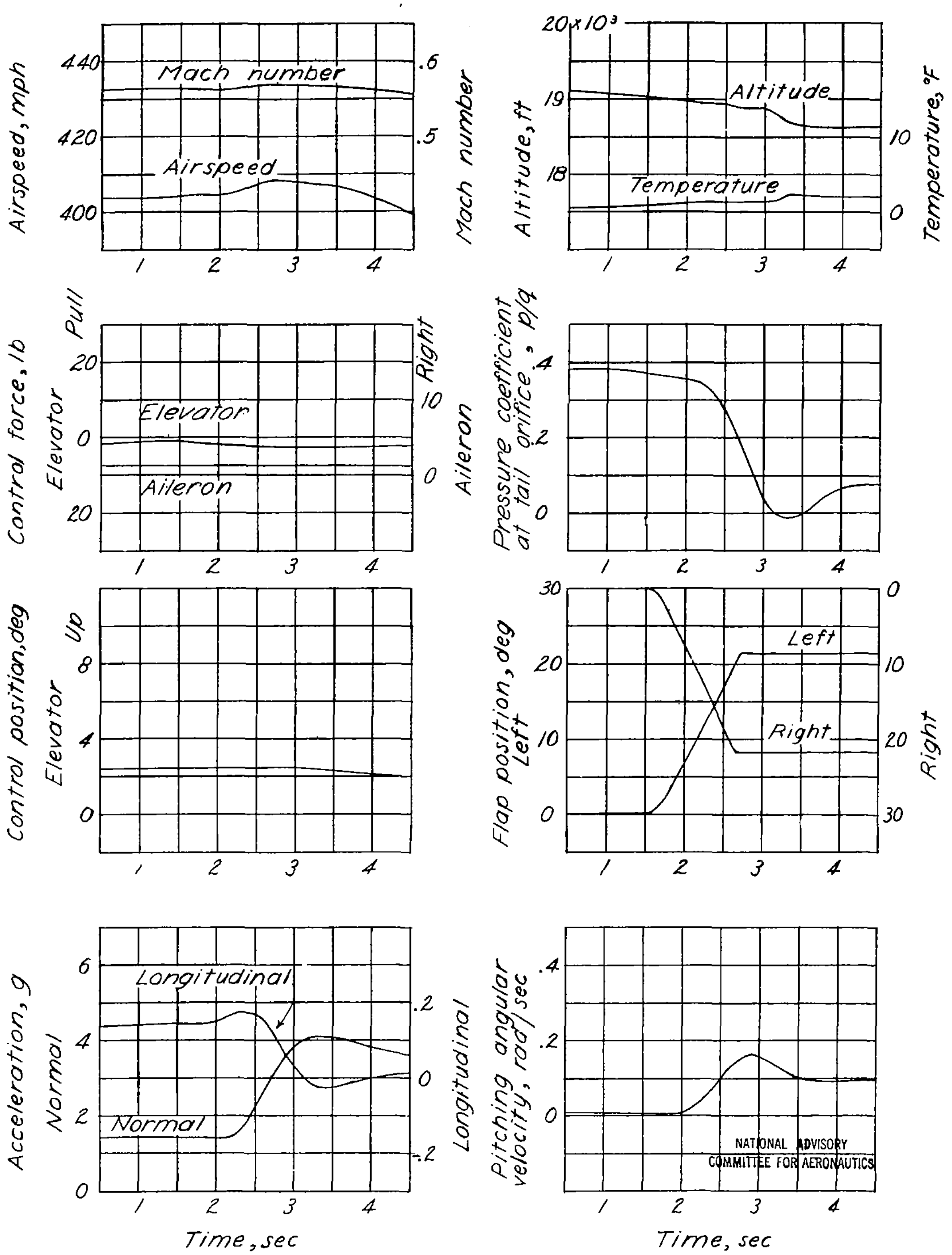


Figure 17.- Variation of basic measured quantities during dive-recovery-flap deflection. Dive-recovery-flap deflection, 21.5°; weight, 7720 pounds; center-of-gravity position, 27.97 percent mean aerodynamic chord.

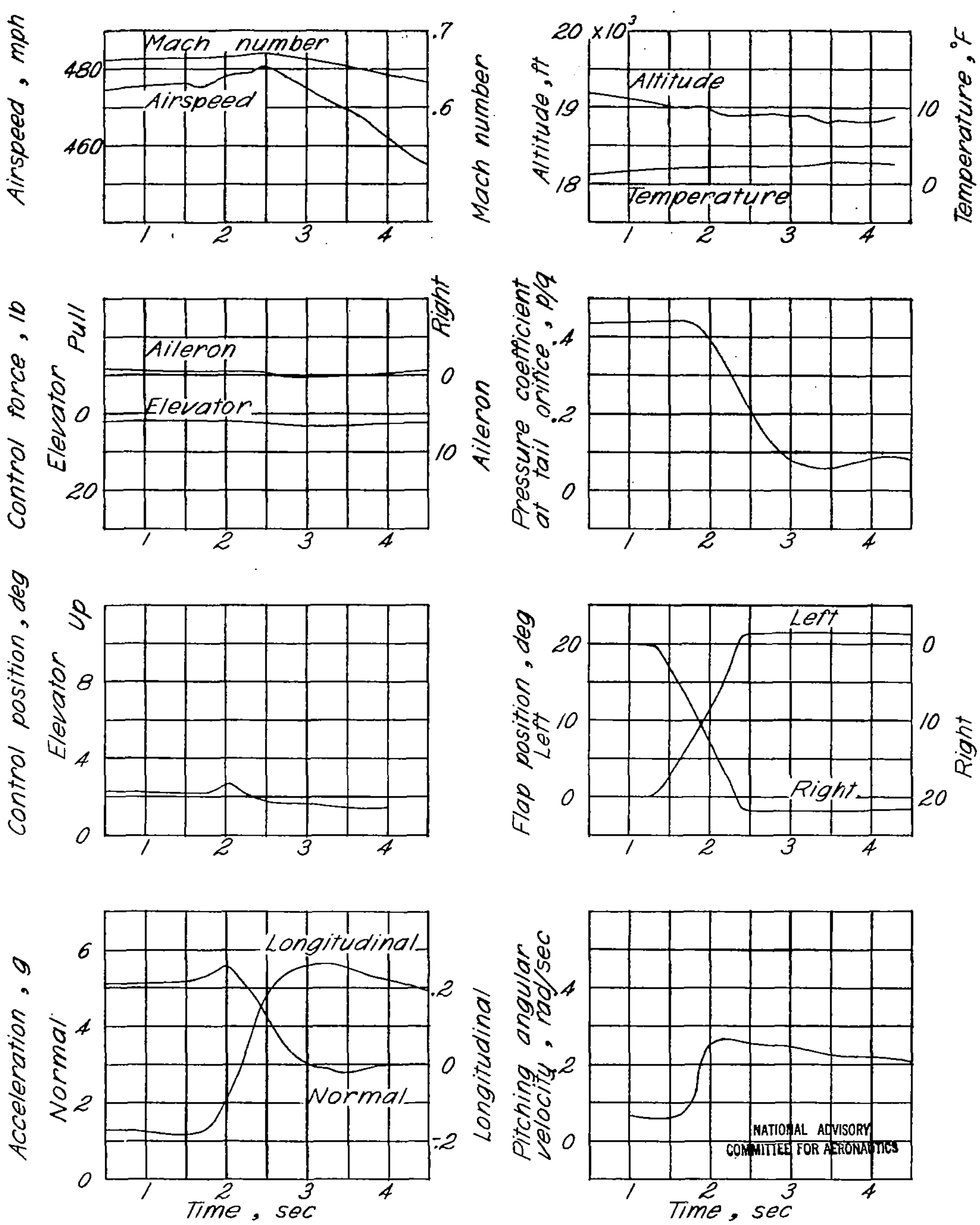


Figure 18.- Variation of basic measured quantities during dive-recovery-flap deflection. Dive-recovery flap deflection, 21.5°; weight, 7840 pounds; center-of-gravity position, 28.28 percent mean aerodynamic chord.

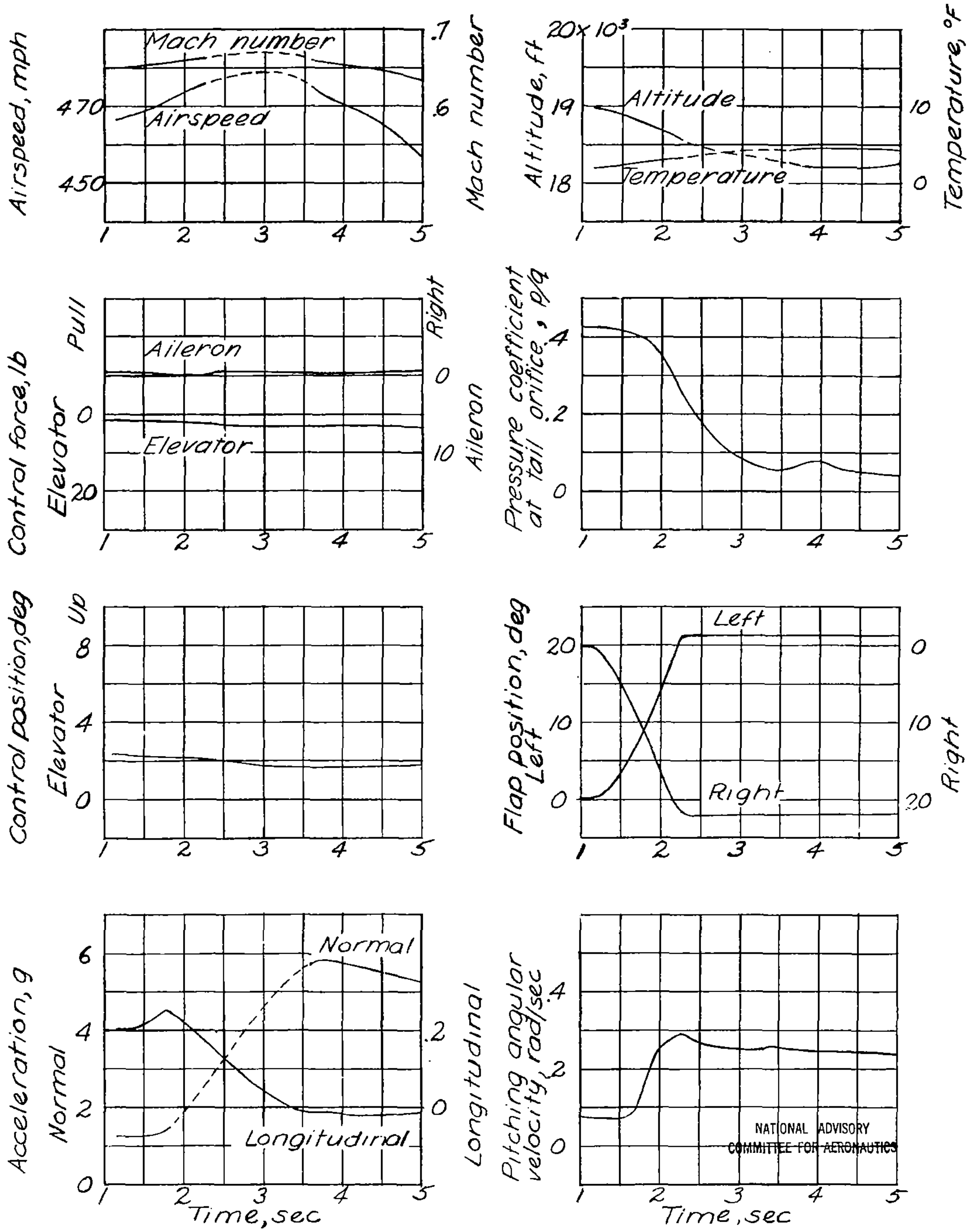


Figure 19.- Variation of basic measured quantities during dive-recovery-flap deflection. Dive-recovery-flap deflection, 21.5°; weight, 7780 pounds; center-of-gravity position, 28.12 percent mean aerodynamic chord.

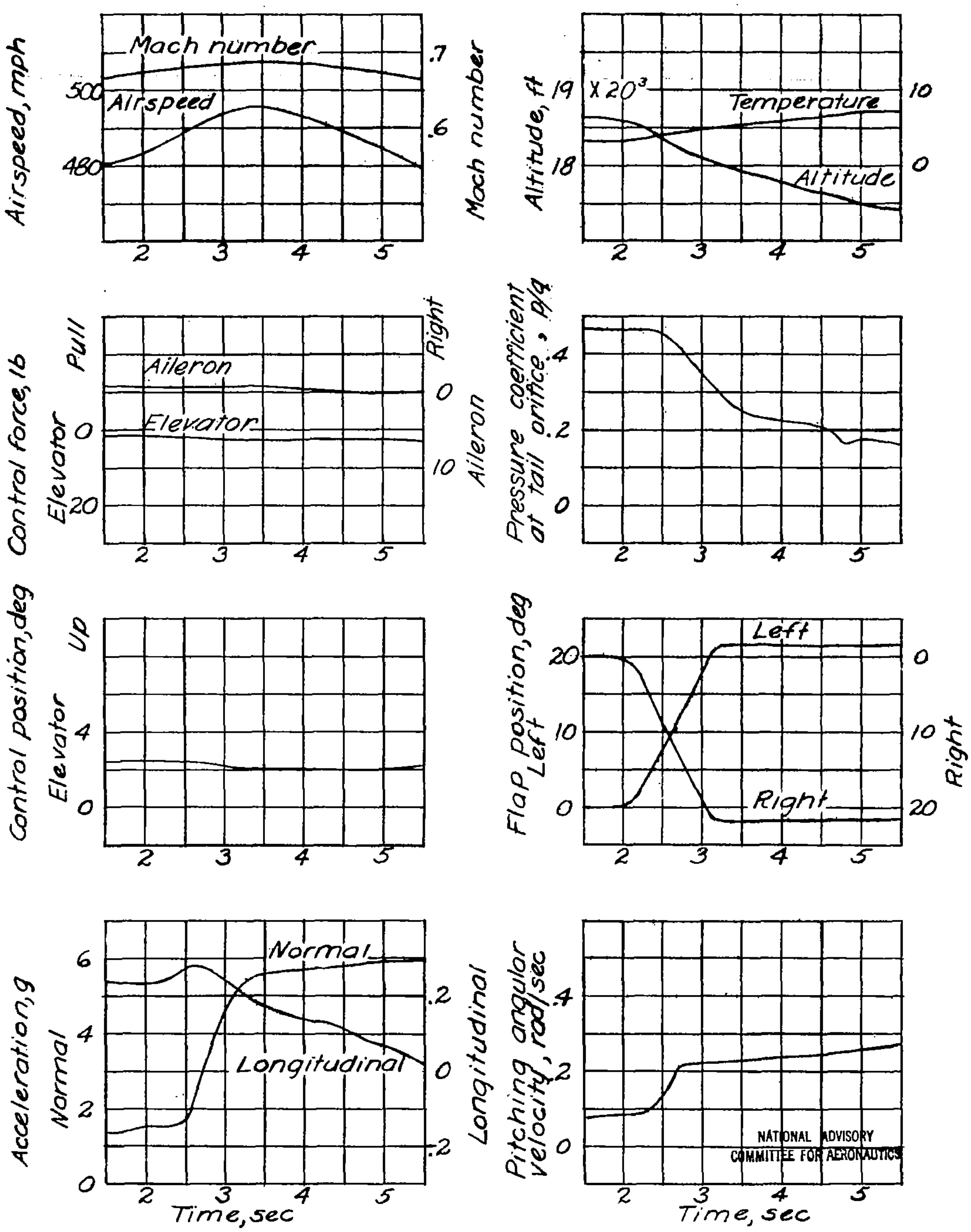


Figure 20.- Variation of basic measured quantities during dive-recovery-flap deflection. Dive-recovery-flap deflection, 21.5°; weight, 7720 pounds; center-of-gravity position, 27.97 percent mean aerodynamic chord.

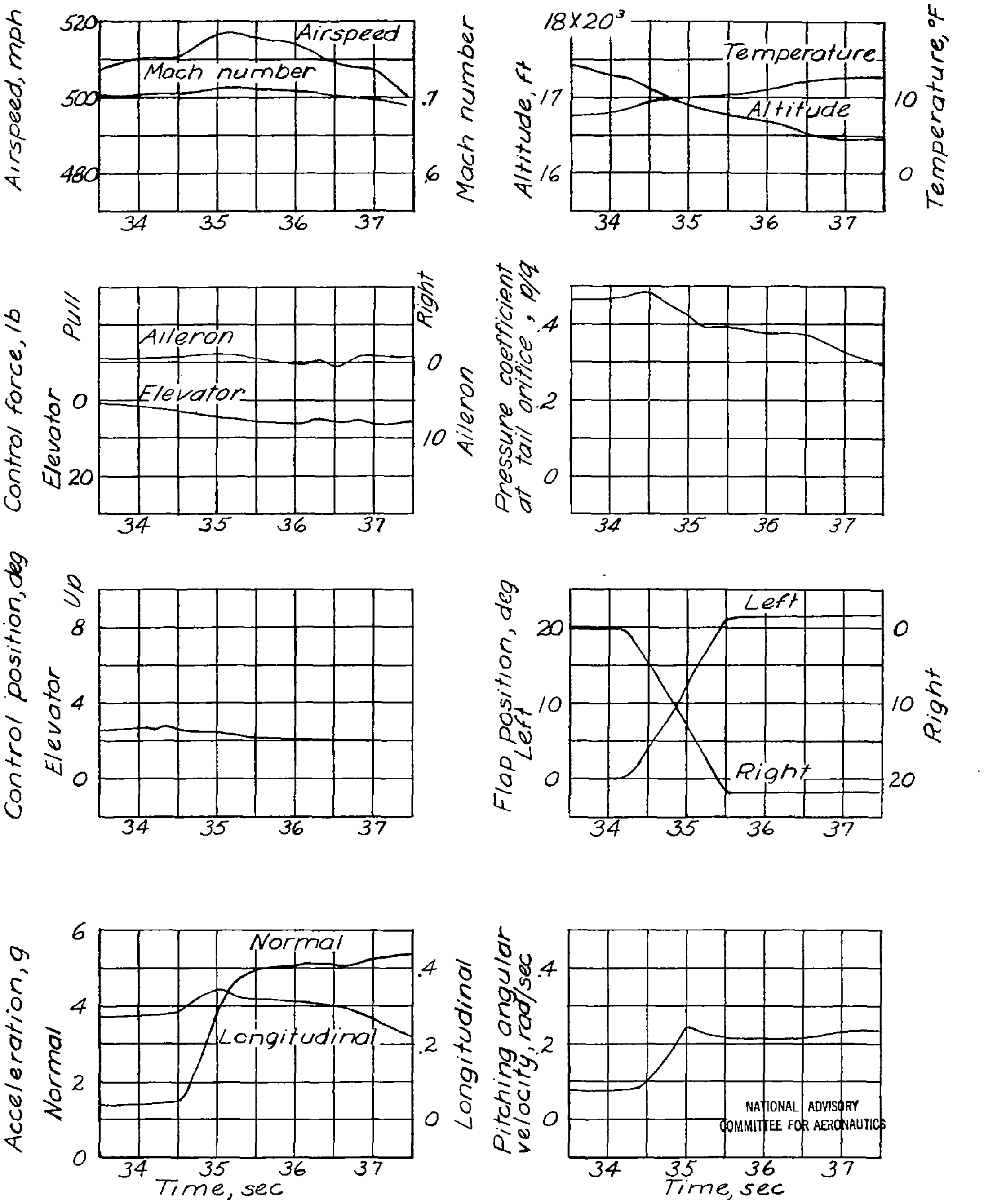


Figure 21.- Variation of basic measured quantities during dive-recovery-flap deflection. Dive-recovery-flap deflection, 21.5°; weight, 7660 pounds; center-of-gravity position, 27.81 percent mean aerodynamic chord.

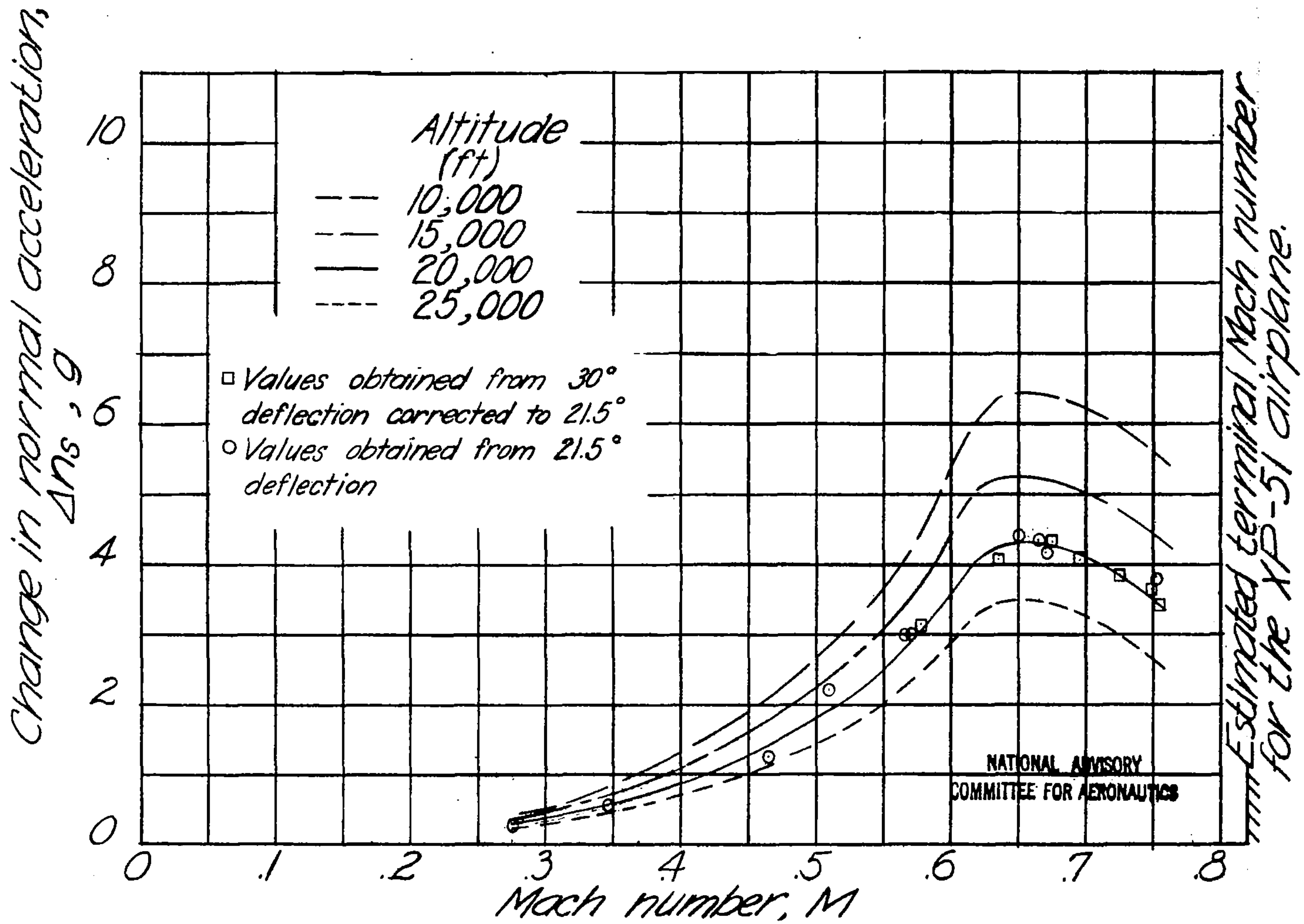


Figure 22.- Variation of normal acceleration due to use of the dive-recovery flaps with Mach number at various altitudes. Dive-recovery-flap deflection 21.5°; XP-51 airplane.

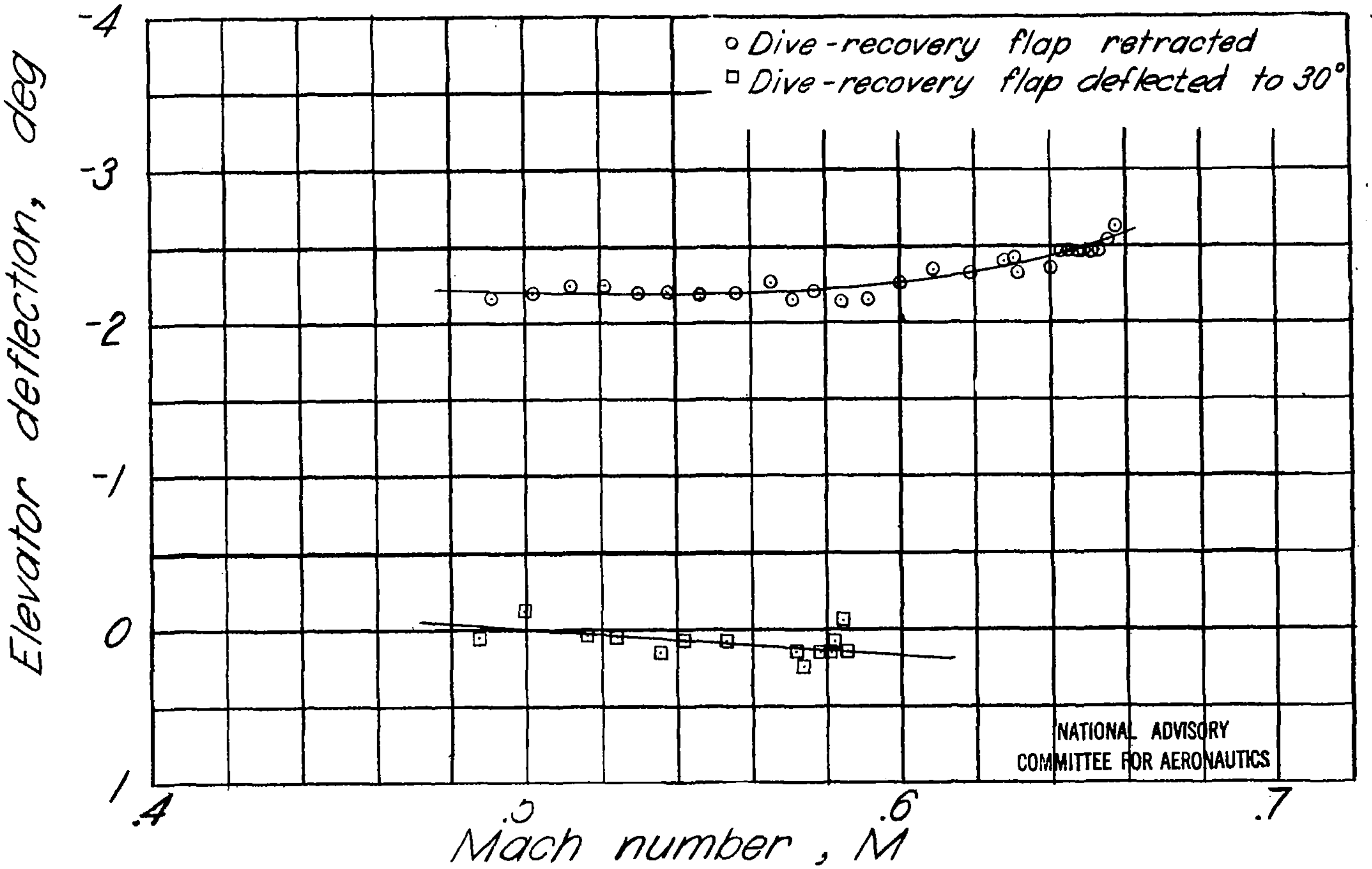


Figure 23.- Elevator deflection required to maintain trim during dive with dive-recovery flaps deflected and with dive-recovery flaps retracted.